North Coast Watershed Assessment Program

Gualala Watershed Synthesis Report

The mission of the North Coast Watershed Assessment Program is to conserve and improve California's north coast anadromous salmonid populations by conducting, in cooperation with public and private landowners, systematic multi-scale assessments of watershed conditions to determine factors affecting salmonid production and recommend measures for watershed improvements.

DRAFT

Gualala Watershed Profile

Introduction

The Gualala River drains 298 square miles along the coast of southern Mendocino and northern Sonoma Counties. The river enters the Pacific Ocean near the town of Gualala, 114 miles north of San Francisco and 17 miles south of Point Arena. The Gualala River watershed is elongated, running over 32 miles long north-south, with an average width of 14 miles. Elevations vary from sea level to 2,602 feet at Gube Mountain and terrain is most mountainous in the northern and eastern parts of the basin (Figure. 2). A long history of movement along the San Andreas Fault and the Tombs Creek Fault has been a dominant force in the shaping of the basin. The climate is influenced by fog near the coast with seasonal temperatures ranging between 40 to 60 degrees F, with the interior basin ranging from below freezing to over 90 degrees F seasonally. Rainfall also varies by location within the basin with 33 inches falling on average near the town of Gualala and totals reaching over 63 inches in some areas within the interior.

The five principal Gualala subbasins in order of size are the Wheatfield Fork (37% of drainage), South Fork and Gualala Mainstem (21%), North Fork (16%), Buckeye Creek 14%), and Rockpile Creek (12%), which also serve as subbasins for analysis in this study (Figure. 2). The mainstem Gualala extends only from the convergence of the North Fork and South Fork to the ocean, with much of this reach comprising the estuary or lagoon. Coastal conifer forests of redwood and Douglas fir occupy the northwestern, southwestern and central portions of the watershed while oak-woodland and grassland cover many slopes in the interior basin. Coho naturally inhabited the streams flowing from coniferous forest but were likely sub-dominant to steelhead in interior basin areas draining the mélange due to the more open nature of the channels, less suitable habitat, and naturally warmer stream temperatures. The interior basin is largely grassland with scattered oaks. Surface water in this area generally lack shade and are warmed with abundant sunshine.

Salmon / Stream / Watershed / Land Use Relationships

Anadromous Pacific salmonids are dependent upon a high quality freshwater environment at the beginning and end of their life cycles. As such, they thrive or perish depending upon the availability of cool, clean water, free access to migrate up and down their natal streams, clean gravel for successful spawning, adequate food supply, and protective cover to escape predators and ambush prey. These life requirements must be provided by diverse and complex instream habitats as the fish move through their life cycles. If any of these elements are missing or in poor condition at the time a fish or stock requires it, their survival can be impacted. These life requirement conditions can be identified and evaluated on a spatial and temporal basis at the stream reach and watershed levels. They comprise the factors that support or limit salmonid stock production.

“In streams where fish live and reproduce, all the important factors are in a suitable (but usually not optimum) range throughout the life of the fish. The mix of environmental factors in any stream sets the carrying capacity of that stream for fish, and the capacity can be changed if one or more of the factors are altered. The importance of specific factors in setting carrying capacity may change with life stage of the fish and season of the year,” (Bjorrn and Reiser, 1991).

Through the course of the years, natural climatic, watershed hydrologic responses, and erosion events interact to shape freshwater salmonid habitats. These include the kind and extent of the watershed’s vegetative cover as well, and act to supply nutrients to the stream system. “In the absence of major disturbance, these processes produce small, but virtually continuous changes in variability and diversity against which the manager must judge the modifications produced by nature and human activity. Major disruption of these interactions can drastically alter habitat conditions.” (Swanston, 1991).

The results of a major disruption, which can be created over time by many smaller disruptions, can drastically alter instream habitat conditions and the aquatic communities that depend upon them. Thus, it is important to understand the critical, dependent relationships of salmon and steelhead with their natal streams during their freshwater life phases, and their streams' dependency upon the watersheds within which they are nested, and the energy of the watershed processes that binds them together.

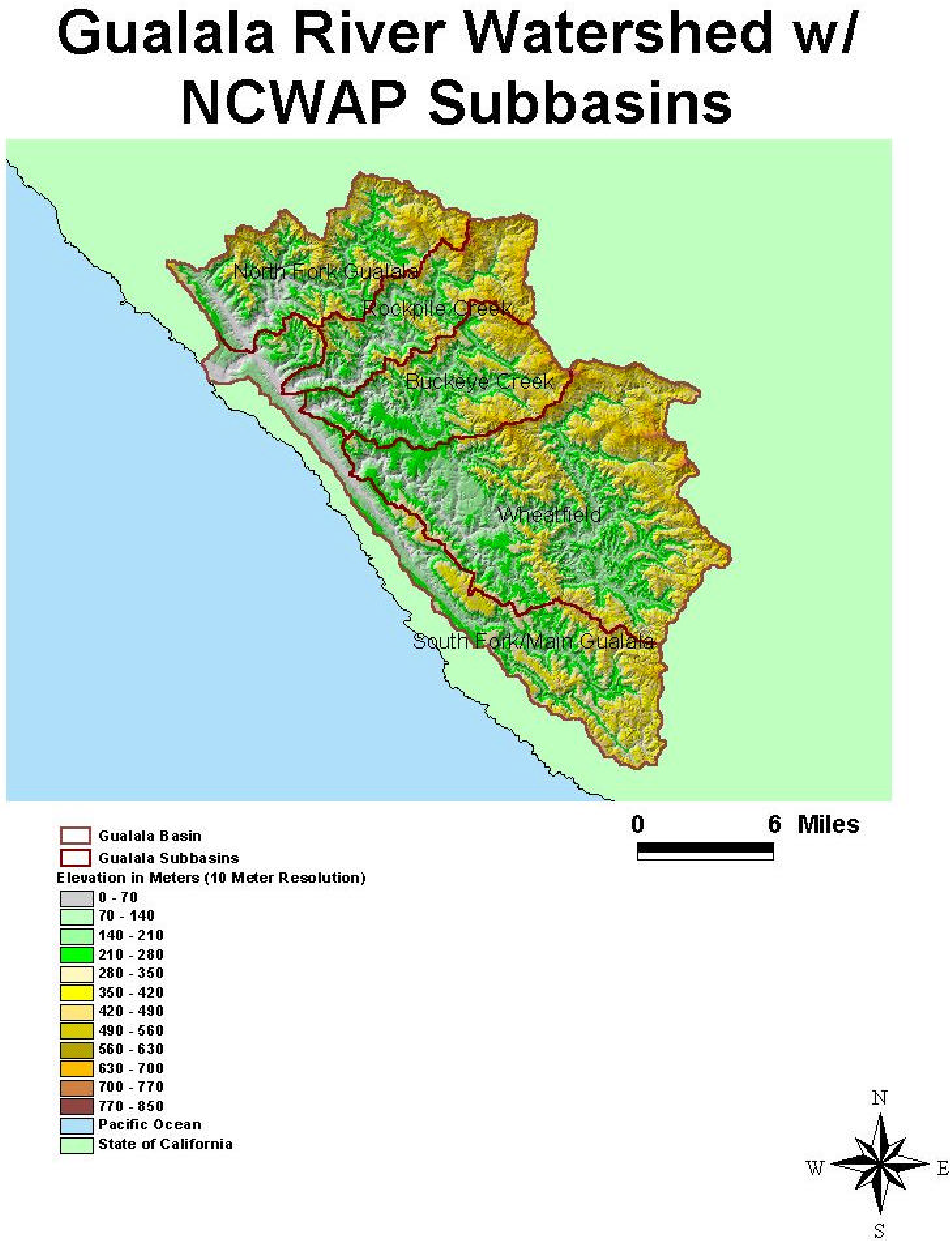


FIGURE 2: GUALALA RIVER WATERSHED W/ NCWAP SUBBASINS

"Protection and maintenance of high-quality fish habitats should be among the goals of all resource managers. Preservation of good existing habitats should have high priority, but many streams have been damaged and must be repaired. Catastrophic natural processes that occlude spawning gravels can reduce stream productivity or block access by fish (for example), but many stream problems, especially in western North America, have been caused by poor resource management practices of the past. Enough now is known about the habitat requirements of salmonids and about good management practices that further habitat degradation can be prevented, and habitat rehabilitation and enhancement programs can go forward successfully," (Meehan, 1991).

In general, natural disruption regimes do not impact larger watersheds, like the 298 square mile Gualala, in their entirety at any given time. Rather, they rotate episodically across the entire mosaic of their smaller subbasin, watershed, and sub-watershed components over long periods of time. This creates a mosaic of habitat conditions over the larger watershed, (Reice, 1994).

Human disturbances, although individually small in comparison to natural events, are usually spatially distributed widely across basin level watersheds, (Reeves, et al., 1995). That occurs because market driven land uses tend to function in temporal waves, like the California Gold Rush or the post-WWII logging boom in Northern California. The intense human land use of the last century, combined with the energy of two mid-century, record floods on the North Coast, created stream habitat impacts at the basin and regional scales. The result has overlain the natural disturbance regime and depressed stream habitat conditions across most of the region.

Subbasin Scale

Natural variation in subbasins is at least partially a product of natural and human disturbances. Other variables that can distinguish areas, or subbasins, in larger basins include differences in elevation, geology, soil types, aspect orientation, climate, vegetation, fauna, human population, land use and other social-economic considerations. The combined complexity of large basins makes it difficult to speak about them concerning watershed assessment and recommendation issues in other than very general terms. In order to be more specific and useful to planners, managers, and landowners, it is useful to subdivide the larger basin units into smaller subbasin units whose size is determined by the commonality of many of the distinguishing traits.

Hydrology

The watershed has a long history of land use, fire, and floods. With steep slopes and high rainfall amounts, alterations of the landscape can likely change the hydrologic curves, flood frequencies and stream flow peaks within the subwatersheds. Aggradation of the streambed in many areas has probably reduced surface water flow during dry years.

The main stem of the Gualala River flows from the confluence of the South Fork and North Fork to the Pacific Ocean. This reach is greatly influenced by seasonal closures of the river mouth, which typically occur in early summer and last until the first heavy rains of October or November, although it may also close briefly during the winter months (CDFG 1968 and EIP 1994).

Precipitation in the Gualala watershed is highly seasonal. Most precipitation occurs between the months of October through April. Average annual precipitation ranges from 33 inches at the lower elevations near the Pacific Ocean to 63 inches at the higher elevations in the southeastern upper watershed.

Few long-term precipitation stations exist within the basin. The longest gauge record near the basin is the Cloverdale gauge with a continuous period of record of 1903 through the present. Annual precipitation at the gauge during this period ranged from 13.54 inches in 1924 to 79.26 inches in 1983. Mean annual precipitation for this station is 40.89 inches. A list of long-term precipitation gauges within or near the Gualala watershed and a location map are included in Appendix 6.

Similar to other watersheds within the North Coast, only a few stream flow gauging stations have historically operated within the Gualala watershed. Stream flow data had not been collected by any agency since 1994. To gain additional stream flow data, three stream flow gauging stations (one on the North Fork Gualala, one on the Wheatfield Fork, and one on the South Fork Gualala above the Wheatfield Fork) were installed by NCWAP during the fall of 2000. Zero flow occurred at the new Wheatfield and South Fork gauges during the late summer months of 2001, but the North Fork maintained a minimum base flow and was the major if not the only contributor of surface water flow to the estuary during low flow periods. A list of existing and discontinued stream flow gauging stations, their locations, and period of record along with a location map are provided in Appendix 6.

Only one stream flow gauge, USGS gauge #11467500 "South Fork Gualala River near Annapolis" was operated for a significant continuous period (October 1950 – September 1971). This station was located below the confluence with the Wheatfield Fork and measured the runoff from a drainage area of 161 of the 298 square mile Gualala watershed. The two highest peak flow events recorded for this station occurred in December 1955 at 55,000 cubic feet per second (cfs) and January 1966 at 47,800 cfs. While other North Coast rivers experienced near record flood flows in December 1964, the South Fork Gualala gauge recorded only 21,000 cfs. An examination of other stream flow gauges in the area indicates recent flood events at the South Fork Gualala gauge site of 30, 000 cfs or greater probably occurred in 1974, 1983, 1986, 1993, 1995, and 1997. A summary and statistical analysis of the flow data for this station are presented in Appendix 6.

A search of the SWRCB's Water Right Information System (WRIMS) was performed to determine the number and types of water rights within the Gualala watershed. The WRIMS database is under development and may not contain all post-1914 appropriative water right applications that are on file with the SWRCB at this time. Some pre-1914 and riparian water rights are also contained in the WRIMS database for those water rights whose users have filed a "Statement of Water Diversion and Use". A list of water rights and associated information contained within WRIMS for the Gualala watershed along with a location map are presented in Appendix 6.

SWRCB issued appropriative water rights for a total of about 4,500 acre-feet per year (ac-ft/yr) of water from the Gualala River watershed, at a maximum diversion rate of about 8 cfs. Because the watershed is sparsely populated, riparian extraction in the watershed is probably minimal. The potential peak demand from this use and additional future riparian uses in the watershed was estimated to be 2.5 cfs (EIP, 1994). Although municipal use is the dominant water use in the watershed, other uses of surface water include domestic, irrigation, stock watering, fish and wildlife enhancement, and fire protection.

Current water use in the Gualala River watershed by agricultural and rural development is probably minor. However, as stated in the Gualala River Watershed Literature Search and Assimilation (Higgins 1997): "While agricultural water use in the Gualala River watershed has been very low in the past, vineyards are now being developed in some areas. These" vineyards "may have a direct impact on tributary flow if surface water is used. If wells are drilled in upland areas, and if the aquifer is joined to headwater springs, flows in some tributaries could be affected". EIP Associates (1994) projected that development of vacation homes or residences could result in use of up to 2.5 cfs for the entire basin.

Two major municipal water users, the North Gualala Water Company (NGWC) and the Sea Ranch, currently extract water from the Gualala watershed. The SWRCB issued an appropriative water right permit to NGWC to divert water from the North Fork Gualala River. The permit stipulates a maximum diversion of 2.0 cfs, but when the natural flow of the North Fork falls below stipulated by-pass flows for fish, NGWC is prohibited from diverting any water from the North Fork. The by-pass flows vary with the time of year, but a minimum by-pass flow of 4.0 cfs is required at all times. In August 2000, the State Water Resources Control Board ruled that the by-pass flows applied to both surface water diversions and extractions from underground water from two NGWC off-set wells that had been previously found to fall under the SWRCB's jurisdiction as "subterranean streams flowing through known and definite channels". The SWRCB decisions regarding these water extractions are currently under litigation in the Superior Court of Mendocino County. The plaintiff, NGWC, is claiming the water extractions from their off-set wells do not fall under the jurisdiction of the SWRCB.

The Sea Ranch once drew surface water directly from the South Fork Gualala, but they currently draw water from the aquifer below the lower South Fork Gualala riverbed by off-set wells and have augmented storage with an off-site reservoir. The SWRCB again ruled that the water extractions from the aquifer are from "subterranean streams" and are therefore under the SWRCB jurisdiction. The Sea Ranch's appropriative water right permit allows for a maximum extraction of 2.8 cfs, although actual historic maximum diversions have been substantially less. These diversions are also dependent on minimum fish by-pass flows stipulated in the SWRCB permit. Current low flow constraints in the Gualala River will most likely prohibit future additional appropriative water allocations; however, greater use of the rights allocated to the Sea Ranch is expected in the future.

The NCRWQCB's Basin Plan designates ten existing and one potential beneficial use of water for the Gualala River watershed. The Water Board has responsibility for protecting all beneficial uses. Accordingly, the water quality parameters assessed in this report are compared to water quality objectives for the protection of all beneficial uses. However, the assessment is focused primarily on the salmonid fishery beneficial uses: COLD (cold freshwater habitat), SPWN (spawning, reproduction, and/or early development), MIGR (migration of aquatic organisms), EST (estuarine habitat), and REC-1 (water contact recreation-fishing). A complete list of beneficial uses is shown in Appendix 9.

Geology

The Coast Ranges in general and the Gualala Watershed in particular are areas of naturally high background levels of landslide activity due to geologic and climatic conditions; i.e., steep slopes, weak rock, high rainfall, seismic shaking, and uplift. The watershed resides wholly in the San Andreas Fault System and is bounded on the west and east by the San Andreas and the Maacama Faults. Drainage networks are largely fault controlled and vary from very long linear reaches (as along the Little North Fork and South Fork) to regions of simple zigzag patterns (Rockpile Creek), to high ordered convoluted patterns (eastern Wheatfield Fork). A disconnected series of northwest trending interior ridges subdivide the Gualala watershed into several sub-basins. The Geologic and Geomorphic Features Related to Landsliding Map (Plate 1) shows a complex pattern of lithology and landsliding.

The inland boundaries of the watershed and sub-basins are defined by the disconnected series of northwest oriented groups of ridges. Varying distributions of large earthflow and rockslide complexes are mapped (see Plate 1). Northwest oriented bands of poorly consolidated ancient marine terraces are concentrated in lower central and upper east reaches of the watershed. The Ohlson Ranch formation is subject to landsliding along the edges of terraces or along incised drainages.

The Gualala River system and surrounding topography evolved in response to rapid geologic changes along the west coast of North America over the past 30 million years, and especially in the last five million years. The drainage networks evolved along with the changing landscape. The landscape continues to actively change through the processes of erosion and mass wasting in ways that force the stream channels to continually adjust. It is unknown (and beyond the scope of the geologic portion of the assessment) to what degree land use has accelerated natural erosion levels and how long the residual effects will last. It is clear that past land-use practices that were indifferent to stream health triggered many landslides and directly placed large volumes of sediment in the stream channels.

Montgomery (2000) proposed that the geologic evolution of the Pacific coast created habitat diversity, which allowed for the evolution of the five species of Pacific salmon. It then follows that in the Gualala Watershed, the present ecology of the listed coho salmon and steelhead developed in sync with the geologic foundation, and modification to the landscape from historic time. Additional detail is presented in Appendix 7.

Land Use

The Gualala Watershed has one of the longest span of historical use compared to other North Coast watersheds. Logging of the virgin old growth redwood forest began during the mid 1800s. The first documented account dates to 1862 in lower portions of the watershed near coastal ramp and port facilities. This includes the lower reaches of the Little North Fork, North Fork, Pepperwood Creeks, and the lowest reaches of Rockpile and Buckeye Creeks at the confluence with the South Fork. There was concentrated demand of the resource after the 1906 earthquake and rebuilding of San Francisco. The first logging methods used oxen teams to move large old growth redwood logs to terminal points of lateral connecting rail lines, which extended along the South Fork to Gualala from the Santa Rosa Area. Watercourses were frequently used to move logs downslope including use of splash dams. Main rivers were used to float logs downstream. Fire was used extensively to reduce slash during logging and in attempts to convert redwood forest to grazing land after the logging.

Early logging activities left a legacy of impacts, some of which persist to the present. Splash dams and log drives tended to flatten and simplify stream channels. Rail line construction included massive cut and fill excavation along roadbeds which followed streams. Although wood trestles were built over larger watercourses, smaller watercourses were crossed by wood and earth fill which later failed. The introduction of the steam donkey by the turn of the century reduced ground impacts by cable pulling arge logs from fixed locations but allowed much more widespread forest harvest. These operations did not disturb the ground to the extent of more recent tractor operations characterized by large-scale sideslope excavations and skid trail networks. The gasoline powered crawler tractors made their appearance in the north coast in the late 1920s, but logging in the Gualala was inactive during the Great Depression.

Increased demand for lumber products during the 1950s coincided with the widespread deployment of heavy tractors greatly improved by technology advanced during World War II. Early versions of the D-8 and D-10 tractors, using refined track mounts and suspension systems, and powered by diesel engines, were ideally suited for moving large diameter logs over difficult terrain. This equipment was readily maneuverable, enabling large areas to be worked over in short time periods. Rail line networks were quickly abandoned and diesel powered log trucks transported logs along seasonal roads. Between 1952 and 1960, tractor method harvesting extended in a broad sweep from the upper reaches of the North Fork, east through the central and upper reaches of Rockpile and Buckeye creeks, and throughout lower and middle reaches of Wheatfield Fork. Harvest operations followed straight parcel lines regardless of watercourse condition or difficult terrain. Roads often followed the stream channel to enable downslope skidding. Many roads had steep gradients designed to access all positions of the sideslope. Skid trails frequently followed or crossed ephemeral stream channels. Landings were often located in, or adjacent to, watercourses. These were built by pushing wood debris into channel, and overtopped by dirt fill. Across steep terrain, skid trials cut deep into the sideslope, creating a terraced effect. By 1964, tractor harvesting had continued at an active pace to comprise a majority, and in some areas, most of the timbered areas in the west and central reaches of the watershed (See Figures 3, 3a-b below).

The lack of any erosion control facilities installed throughout large areas of the watershed, coupled with the uncontrolled installation of fills and failure to remove fills adjacent to watercourses, left the entire watershed particularly vulnerable to the 1964 flood event. During a period of one week in December 1964, the intense prolonged runoff caused massive erosion from downcutting, slides, and washing of soil and debris into watercourses. The residual effects are still observed in some areas today. Cal Trans aerial photos taken in June 1965 at 1,200 scale show stream channel meandering through wide, flat areas of buried stream pools, indicating channel aggradations. Roads following the stream channel repeatedly failed as fill sidecast washed out during peak flows. Debris slides above and below roads were frequent. Deep blowouts through landings built over channel are numerous throughout the 1965 photos. There were numerous watercourse diversions onto roads and skid trails.

After 1964, harvest operations resumed at an active rate in the lower and middle reaches of the North Fork and entire Little North Fork areas to remove most of the available timber base in these areas by 1973. Other areas of mature Douglas fir in (1) higher elevation areas and (2) east reaches of the watershed were harvested during this time. Only pocket stands and scattered larger timbered blocks remained. Roads and landings continued to be located low on the sideslope, frequently following the stream channel. Subsequent landing blowouts and road failures have been documented along the Little North Fork and central North Fork. There were large storm events in 1972 and 1974. With ranching being the dominant use in mixed conifer –oak woodland areas, logging of Douglas fir was frequently followed by prolonged cattle grazing. This reduced, and in many locations prevented conifer reestablishment altogether. Grassland became permanently established throughout compacted ground. In addition, removal of Douglas fir in mixed conifer-hardwood forests converted these stands to pure tan oak and madrone. Prolonged cattle grazing in riparian areas after harvest prevented timely reestablishment of canopy cover over fish bearing watercourses, elevating stream temperatures.
After 1973, logging operations had slowed. Smaller selection method harvests were predominant. By this time, tractor-yarding methods changed to maintain equipment exclusion zones and minimum vegetation retention standards adjacent to watercourses per 1973 Forest Practice Rules. New road locations were moved upslope, but the practice of using existing roads located near streams continued. The new forest practice rules limited the cutblock size, creating smaller logged areas.

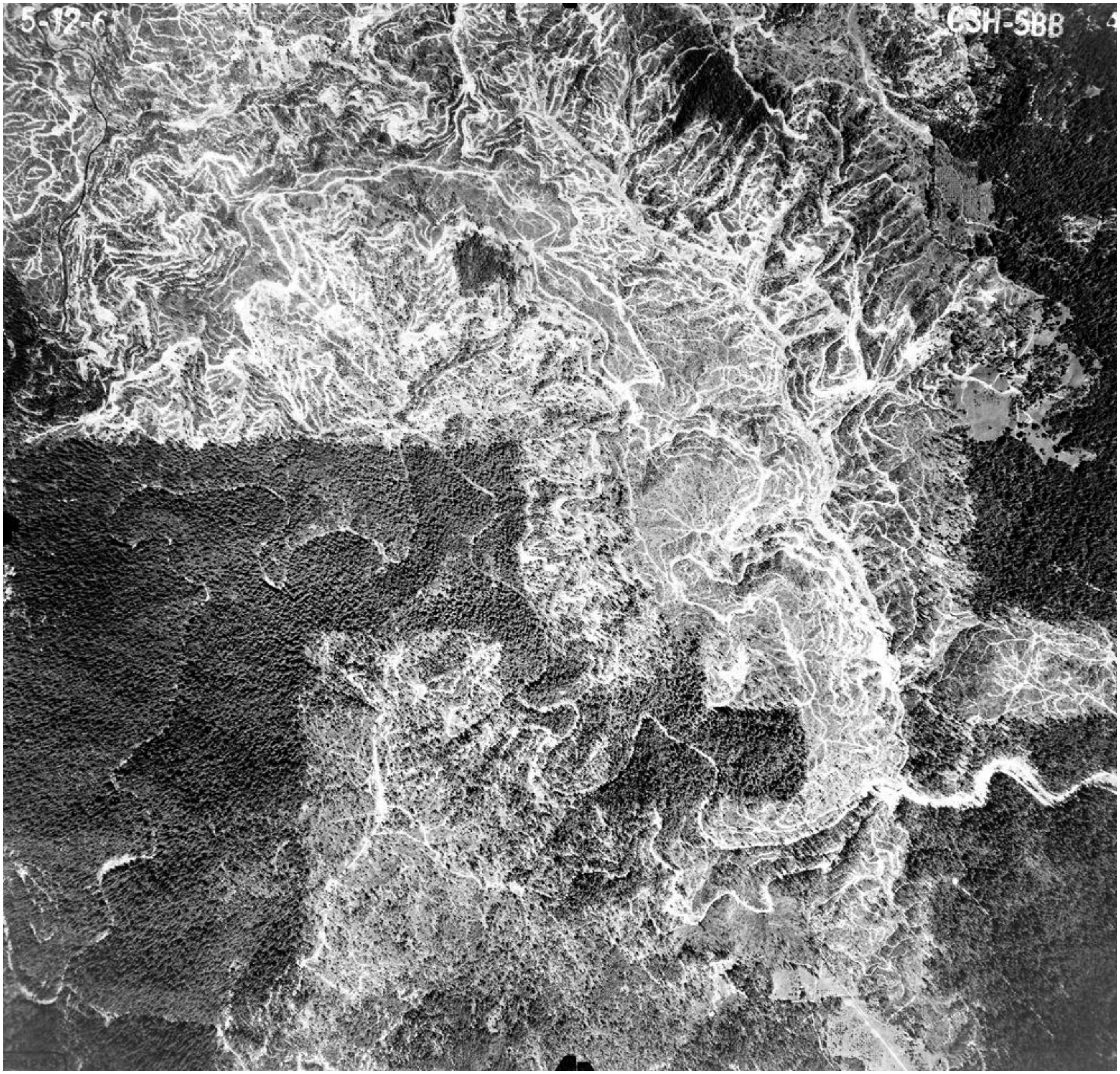
In the 1990s, harvest activity increased. Smaller but numerous clearcut blocks appear in the redwood lowland areas of the Gualala Redwoods ownership. Throughout the watershed, cable method yarding appears with new road construction now moved to upslope and ridgeline locations. Many sections of the older seasonal roads following the stream channel are either abandoned or removed. Numerous seasonal roads still exist in close proximity to streams, and are used as needed during timber harvest activities. During the mid 1990s, Coastal Forestlands (formerly R&J Timber Co.), purchased by Pioneer Resources in 1998, submitted numerous seed tree overstory removal/ dispersed harvest THPs, covering large areas but removing scattered single trees and remnant stands left from 1960s era entries. Agency review of these THPs clarified road upgrade work requirements to repair erosion conditions of pre-1973 operations. There has been little harvesting in these areas since 1998. Residential development near the coast, and vineyard development inland, become dominant land use activities by the late 1990s. Ninety-five per cent of the Gualala watershed is privately owned.

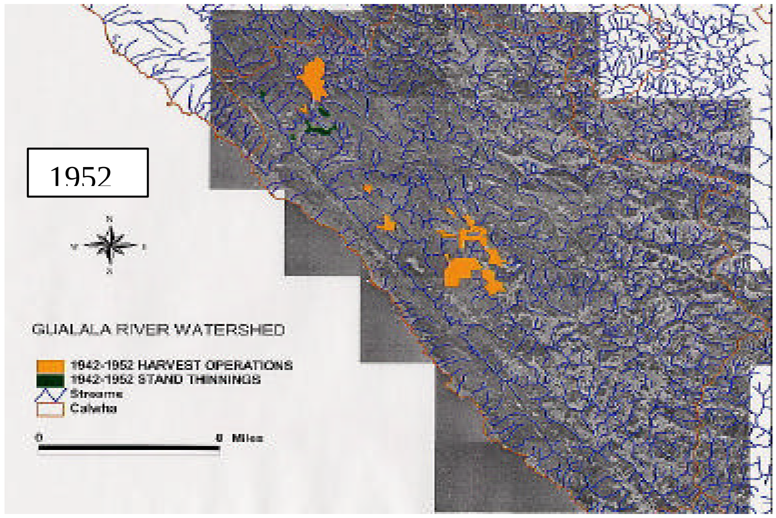
General Watershed Findings

1. Most current riparian overstory conditions reflect shade canopy in-growth of young conifer/ hardwood regeneration from riparian zones entirely cleared of all vegetation between 1952 and 1968. However, a full rotationary time period will be needed within WLPZs to fully reinstate overstory canopy strand structure of late seral trees to coincide with post Depression 1936-1942 era overstory canopy cover. In 30 to 40 year old conifer plantations in higher reaches of the watershed, entire bank to bank shade canopy cover has been reinstated over smaller streams. After initial land clearing and forest removal, prolonged pasture grazing spanning decades in the northeast and east areas of the watershed prevented timely reestablishment of canopy cover over watercourses. With the decline of ranching in recent years, young sapling sized conifers/ hardwoods have reestablished in riparian areas

FIGURE 3: 1961 aerial photo, Post World War II

Pre-Forest Practice Rules logging in the Buckeye Creek Subbasin. Franchini Ck. and a new streamside road are in upper right





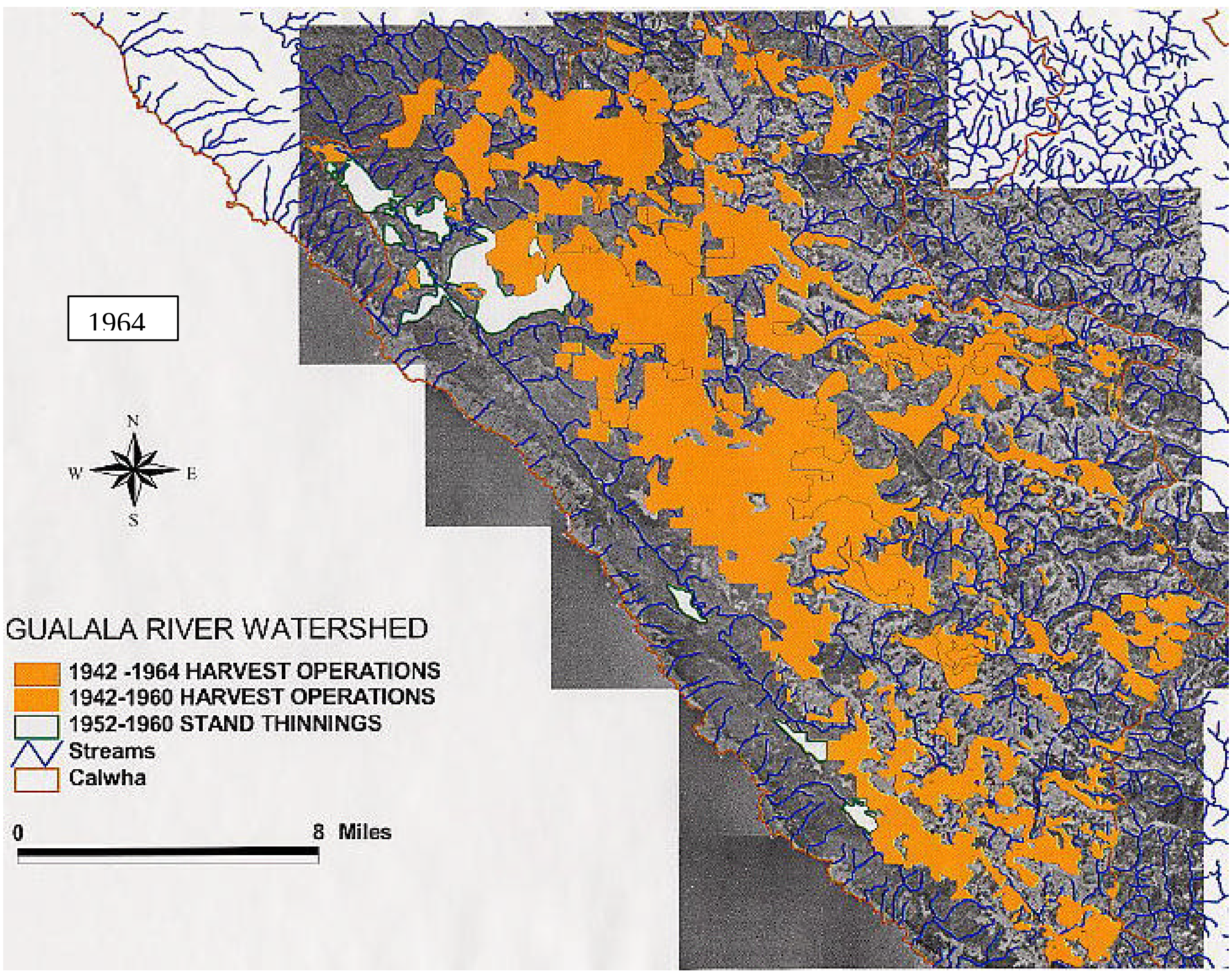


FIGURE 4. Harvest Operations 1942-1960

In a period of only twelve years between 1952 (top) and 1964 (below), heavy tractors eliminated most of the conifer dominated timberstand in the watershed. The 1964 flood rained down on vast areas of recently exposed ground with no erosion controls installed. Streamside roads and landings were built in or adjacent to most major watercourses in these areas.

2. The 1964 storm event rained down on large sub basin-wide timber harvest block areas. These areas were tractor yarded regardless of sideslope condition with no erosion control facilities installed or proper disposal of sidecast effected. This caused massive erosion, slides, and washing of soil and debris into watercourses. Sedimentation, pool infill, and stream widening have been documented at the point of discharge immediately after the 1964 flood. In steeper terrain, for example in the N.F/ SF. Fuller Creek and higher reaches of the North Fork and Rockpile sub-basins, sedimentation debris has washed downstream to low lying alluvial basins, per 1984 and 1999 photos and field observations, re-exposing a rocky substrate upstream to varying degrees. This substantiates more detailed studies of post 1964 sediment transport studies on Redwood Creek, which shows that sediment was dispersed downstream over time and deposited in lower energy environments on the flood plains and in the stream channels.

3. A shallow pool structure generally predominates in moderate gradient tributary streams. In these lower energy gradient environments, low stream pool frequency and shallow pool depth coincide with contemporary fisheries studies showing predominantly young of the year steelhead populations and absence of coho. This contrasts with the earliest fisheries studies dating back to the early 1960s showing deeper and more frequent pool structure with consistent coho observations, and older steelhead found in these many of these same areas. This is particularly noted adjacent to late 1950s/ early 1960s tractor areas that continue to discharge debris into watercourse during large storm events, i.e. Buckeye and Wheatfield Basins. The extent to which that recovery is slowed by current land use practices, interacted with more recent storm events, is unknown. However it is apparent that instream conditions noted in these areas are not fully supportive of anadromous salmonids today.

GENERAL RECOMMENDATIONS

1. Decommission or upgrade roads to minimize the potential for additional debris and sediment inputs to watercourses. This assessment finds that streamside roads and landings built 40 to 50 years ago are heavily concentrated in the watershed, and are a high priority need for stabilization. The Logging Impacts Map shows specific locations The large-scale stabilization program carried out in Fuller Creek is exemplary in promoting the recovery of the aggraded stream channel conditions in an area identified with the worst of the logging related damage in the watershed. Recommendations for road abandonment and improvements are:

2. Properly size all road watercourse crossings based on the 100 year return period standard recently implemented, and install bridge crossings over all Class I watercourses to reduce the potential for failure and washout.

3. Increase size and density of trees and promote replanting in the riparian corridors in the entire Gualala River watershed, especially in the eastern areas predominated by oak woodland and chaparral, and the Wheatfield Fork subbasin

Vegetation

Prior to European settlement, coniferous forest extended throughout approximately two thirds of the watershed. Dense old growth redwood forests occupied the northwestern portion of the watershed, particularly the alluvial North Fork sub-basin. Old growth redwood also lined the long and narrow South Fork valley basin. Douglas fir predominated in central and mid slope locations more distant from the coast.

Further inland in the eastern portion of the watershed, the natural distribution of Douglas fir becomes increasingly fragmented. Here, the long summer drought limits Douglas fir to north facing slopes. The oak-woodland predominates as a more continuous distribution on higher, inland terrain the more distant from the coastal marine influence. Large areas of prairie grassland occupy the driest sites along ridge and upslope locations. These occupy larger continuous areas on the highest and easternmost areas of the watershed.

Fluvial Geomorphology

In response to the 1964 storm, sediment accumulated in many of the upper reaches –the transport reaches. Prior land use, such as in-stream landings and roads, elevated sediment loads. Some of the sediment blocked active channels; the rest become stored outside of the active channel. Subsequently, the accumulated sediment in the active transport channels generally has been dispersed downstream, where its fate is unknown. The rest has been variably vegetated and stabilized but may remain available for remobilization during sufficiently high flows.

Although other recorded peak discharge flood events have exceeded the 1965 water year, data are not readily available for evaluating the relative impact of these individual events on the watershed. An indication of the recent general changes in channel character is being provided in the final DMG report through comparison of reconnaissance mapping from aerial photos taken in the springs of 1984, 1999 and 2000. These maps show that in much of the watershed the length of general channel characteristics indicative of excess sediment (multi-thread channels, numerous lateral bars, eroding banks, etc.) has decreased over the most recent 15 year period.

The Gualala River fluvial system is unique in many ways. In many areas during high flows, tributaries back up and drop sediment at their mouths, which is later incised as flows diminish. This backwater effect was noted in several of the main tributaries and has formed a sediment mound in the active channel. During low flows, stream water percolates though the mound rather than flowing over it. It is unpredictable, at this time, whether future flows will reduce or build these mounds. m

The river persists in transporting and storing sediment even at elevated loads. The residence time of excess sediment accumulated in transport reaches is relatively short (in a geologic sense) and some recovery is apparent over decades. However, excess sediment accumulated in lower depositional reaches is hard to quantify and may remain much longer with only vague evidence of recovery. The Gualala River Watershed was similarly affected by 1964 flood and antecedent logging, and was studied well beyond the scope of this assessment. There, long term channel surveys show sediment delivered during the 1964 flood are still stored in the middle and lower reaches (Oazki and Jones, 1998 and 1999).

Thalweg Surveys

The vertical complexity of the stream channel was measured using thalweg surveys at the GRI GRWC monitoring reaches. GRWC protocols were followed, recoding elevation and distance at every significant change in the streambed through a 1000 foot reach. Elevation was measured with an engineer's level and distance with a 200' tape. Benchmarks and fixed starting and ending points were used to assure that the surveys are comparable from year to year. Area under the thalweg to an arbitrary zero level was calculated to allow accurate comparisons of thalweg elevation between years. Thalweg aggradation or degradation is reported in feet relative to the elevation of the channel in the first year of measurement.

Following a large sediment event, a significant aggradation of the channel (>1') is expected, followed by a slow degradation over the next several years (Madej, 1999). A stable channel is expected to fluctuate a little (< ± 0.5') each year. We have re-measured six thalweg surveys since 1998. No measurement has exceeded ± 0.5' from the original measurement. The thalwegs are fluctuating up and down by a few inches per year. There was a significant event on New Years Day 1997. If it had resulted in lasting channel aggradation, it would be expected that the repeat surveys would show a steady degradation. This has not been the case. Although it has only been four years with no significant stressing events, what has been measured would be consistent with the behavior of a stable channel.

While there are no significant changes in bed elevation at these sites on a year-to-year basis, scouring and redeposition during storm events has not been measured. Such events within any one year can be catastrophic for salmonid embryo survival, destroying or capping redds.

Madej, (1999) suggests using the variation index as a way of quantifying the roughness of a stream and hence its suitability for fish. The variation index is defined as [(standard deviation of residual water depths/bankfull depth) * 100]. A flat wide streambed with sediment filled pools would have a low variation index. A stream with many deep pools interspersed with riffles would have a high variation index. As the streams in the Madej study cleared of flood deposits after major events, the variation index approached or exceeded 20. The extent to which these indices are directly comparable to Gualala River's geology, fluvial network and processes, and hyrdology is not specifically known. However, when the variation index was calculated for the GRI GRWC thalweg survey data using the maximum bankfull depth measured in the DFG 2001 habitat surveys in the Gualala, most of the variation indexes were well above 20.

TABLE 2: VARIATION INDEX

Variation Index of Thalweg Profiles

Watershed Cooperative Monitoring Program

(1998 - 2000)

Watershed	Site Number	Watershed* Size (acres)	Variation Index			
			1998	1999	2000	2001
North Fork Subbasin						
North Fork	473	30,600				36.8
North Fork	204	25,433		43.6		49.6
Little North Fork	404**	4,217				46.8
Little North Fork	203**	1,963	23.1	20.9	20.9	20.2
Robinson	207	1,068		18.2		
Dry Creek	211	4,104	63.3	57.6	58.8	55.6
Dry Creek	212**	3,756			43.8	
Rockpile Subbasin						
Rockpile Creek	221	22,373	19.0	11.9		
Buckeye Subbasin						
Buckeye Creek	223	25,588			46.4	
Buckeye Creek	231	21,198	53.4			
South Fork Subbasin						
South Fork	217**	157,415	39.1		36.5	33.9
South Fork	402**	31,081		21.0		
Pepperwood Creek	218**	1,825	19.5	17.5		

*Watershed size is calculated as the area above the monitoring site.

**Maximum Bankfull depth estimated from cross-section surveys

Water Quality

The water quality analysis included comparison of available data to water quality objectives from the Basin Plan, Total Maximum Daily Load suggested targets, and EMDS dependency relationships (thresholds) and other ranges and thresholds derived from the literature (Table 1). With the exception of the Basin Plan objectives, these ranges and thresholds are not legal regulatory numbers. Rather, they are based on information available at the time and are expected to change as new data and analyses become available.

The D_{50} ranges are based on a study by Knopp (1993) who measured a variety of instream parameters on a number of North Coast streams. He presented results for a group of 18 watersheds judged to have had no human disturbance history or little disturbance within the last 40 years. The mean D_{50} value of this data set was 69 mm. The minimum measured value was 37 mm, and the maximum was 183 mm. The intent in the analyses in this assessment is to evaluate the available data against Knopp's distribution. It is not the intent to suggest 37 mm as a minimum value independent of other information about the distribution of the data.

The temperature range for "fully suitable conditions" of 50-60 F (10-15.6 C) was developed as an average of the needs of several cold water fish species, including coho salmon and steelhead trout. As such, the range does not represent fully suitable conditions for the most sensitive cold water species (usually considered to be coho).

The lethal maximum temperature of 75 F (23.9 C) was derived from literature reviews presented in RWQCB (2000). Peak temperatures are important to consider as they may reflect short-term thermal extremes that, unless salmonids are able to escape to cool water refugia, may be lethal to fish stocks. The literature supports a critical peak lethal temperature threshold of 75 F, above which death is usually imminent for many Pacific Coast salmonid species (Brett, 1952; Brungs and Jones, 1977; RWQCB, 2000; Sullivan, et al., 2000).

TABLE 3: In-channel criteria used in the assessment of water quality data.

Water Quality Parameter	Range or Threshold	Source of Range or Threshold
PH	6.5-8.5	Basin Plan, p 3-3.00
Dissolved Oxygen	7.0 mg/L	Basin Plan, p 3-3.00
Temperature	No alteration that affects BUs [1]	Basin Plan, p 3-3.00
	No increase above natural > 5 F	Basin Plan, p 3-4.00
	50-60 F MWAT [2] – proposed fully suitable	EMDS proposed Fully Suitable Range [3]
	75 F daily max (lethal)	Cold water fish rearing, RWQCB (2000), p. 37
Sediment Settleable matter	Not to cause nuisance or adversely affect BUs	Basin Plan, p 3-2.00
Suspended load	Not to cause nuisance or adversely affect BUs	Basin Plan, p 3-2.00, 3-3.00
Turbidity	no more than 20 percent increase above natural occurring background levels	Basin Plan, p 3-3.00
Percent fines <0.85 mm	<14% in fish-bearing streams [4]	Gualala TSD, CRWQCB (2001)
Percent fines <6.4 mm	<30% in fish-bearing streams	Gualala TSD, CRWQCB (2001)
V* in 3rd order streams with slopes 1-4 % [5]	$\leq$0.15 (mean) <0.45 (max)	Gualala TSD, CRWQCB (2001)
Median particle size (d_{50}) in 3rd order streams of slopes 1-4 %	>69mm (mean) >37mm (min)	Knopp (1993)

[1] BUs = Basin Plan beneficial uses

[2] MWAT=maximum average weekly temperature, to be compared to a 7-day moving average of daily average temperature

[3] EMDS = Ecological Management Decision Support model used as a tool in the fisheries limiting factors analysis. These ranges and thresholds were derived from the literature and agreed upon by a panel of NCWAP experts.

[4] fish-bearing streams=streams with cold water fish species
[6] CDFG=Calif. Department of Fish and Game habitat threshold

The data we compared to these ranges and thresholds from a water quality perspective were:

- Continuous water temperature data from data loggers
- Percent fines < 0.85 mm from McNeil samples
- D_{50} from pebble counts
- Dissolved oxygen, pH, conductance (dissolved solids), nutrients (nitrogen, phosphorus)

Turbidity and suspended solids data were not available for this assessment, and represent a limitation in the water quality part of the assessment. The data and summary plots are included in Appendix 9.

USEPA data from April of 1974 to June of 1988 indicate a moderately hard water oligotrophic stream with pH slightly above neutral, high dissolved oxygen, low dissolved solids, and low nutrients (nitrogen and phosphorus). RWQCB results from 2001 do not differ. There were no large differences among the stations, though South Fork pH and hardness values were somewhat higher than in the rest of the Gualala.

Water temperature is a limiting factor for most of the mainstem areas, and some tributaries. Water temperatures are expressed as the highest of the floating weekly average for the summer (MWAT). Those values were within the proposed "fully suitable" range of 50-60 F in many tributaries in the North Fork subbasin, and in some other small tributaries in other subbasins. Mainstem water temperatures for the larger streams (North Fork, Rockpile, Buckeye, Wheatfield Fork, and South Fork/Main Gualala) were above that range. More relationships by subbasin are provided in subsequent sections of this report.

Streambed substrate size is likely a limiting factor for salmonids. While streambed particle sizes (D_{50}) from 1997-2000 data provided by GRI and GRWC showed some improvements over time in some tributaries, D_{50} values were small in the remaining locations. It is well documented that small streambed particle sizes (gravel and lower) make for a more mobile streambed. Mobile streambeds can reduce salmonid embryo survival by destroying and/or capping the redds (Nawa et al., 1990). Smaller particles can smother salmonid embryos, especially those 6.5 mm and less in diameter (Bjornn, et al 1976).

Aquatic/Riparian Condition

Historic conditions for aquatic habitat in the Gualala River can only be inferred from fragmentary information in CDFG stream surveys from the 1960s and from historic aerial photo reconnaissance of canopy conditions. The stream surveys which are most useful are those that immediately followed World War II, and they revealed comparatively higher pool frequency and depth, and longer reaches of suitable spawning gravels. Post 1950s and 1960s era logging surveys documented a shallow pool structure, reduced pool frequency and water quality problems related to logging debris deposited into streams. Current habitat inventories showed shallower pool structure and reduced frequency on most of the tributaries surveyed throughout the watershed.

Canopy cover was complete in most tributaries as of 1942 indicating advanced regeneration from original old growth logging. Streams in the eastern portion of the Gualala basin had a naturally more open canopy even in 1942 photos. Aerial photos from 1961, 1965, and 1981 showed canopy closure substantially reduced. As of 2001, canopy cover measurements taken during habitat typing surveys show improving canopy closure. Aerial photos from 1999 substantiate these findings. Large wood is deficient in many areas of the Gualala River basin as a result of past timber harvest operations and large wood removal projects aimed at improving fish passage.

Stream buffers are important to the protection of fish habitat for several reasons. With respect to stream temperature, dense trees immediately along a stream provide shade from direct sunshine on the stream surface. Stream buffers with dense canopy also help to reduce air temperature, thus reducing convective heat inputs to streams; however, scientific investigations are still uncertain as to how wide and dense buffers need to be to adequately provide for this microclimate effect.

TABLE 4: Gualala Tributaries Surveyed 2001

Tributary Name	DFG Surveyed length (miles)	Length (Miles)	
		Permanent	Intermittent
Buckeye Creek	18.9	16.0	2.8
Danfield Creek	2.3	4.3	0.0
Doty Creek	1.2	2.7	0.0
Dry Creek	2.1	0.9	0.6
Dry Creek Trib. #1	0.5	0.0	2.9
Haupt Creek	0.4	4.8	0.9
House Creek	10.4	11.8	1.5
Little N. Fork Gualala	3.9	4.1	0.0
Little N. Fork Gualala Trib. 2	1.0	0.0	1.3
Log Cabin Creek	0.3	1.3	0.0
Marshall Creek	4.1	8.3	0.0
McGann Gulch	0.4	0.0	2.0
North Fork Gualala	11.3	13.6	0.0
Palmer Creek	0.1	0.0	1.3
Pepperwood Creek	3.4	3.7	1.1
Robinson Creek	1.5	0.8	1.6
Rockpile Creek	8.5	21.3	0.9
South Fork Gualala	1.6	35.7	0.6
Tombs Creek	7.1	8.5	0.0
Wheatfield Fork Gualala	22.1	28.8	2.6
TOTALS	**101.2**	**166.6**	**20.1**

ADD GIS-based HABITAT FIGURES HERE

Fish Habitat Relationship

Coho and steelhead utilize an anadromous life history strategy. The term anadromous refers fish that spawn in freshwater and migrate to the ocean to grow and mature before returning to freshwater streams to spawn. Anadromous salmonids have diverse life history strategies in order to reduce competition between species and also to increases the odds for survival of species encountering a wide range of environmental conditions in both the freshwater and marine environments. A summary of the life history strategies, and historic and current status the anadromous salmonid population of Gualala River is provided below. Further details are provided in each subbasin discussion. A detailed account of coho salmon and steelhead and life histories is presented in Appendix X.

The Gualala River historically has been an important stream for its runs of coho (silver) salmon and steelhead. Historical records document large coho and steelhead populations. A 1970's U.S. Bureau of Reclamation study of northern California estimated that 75 miles of habitat was available to coho salmon in the Gualala Basin and that 4,000 adults returned annually (U.S. BOR, 1974). The CDFG reported 16,000 steelhead, 4,000 coho and zero Chinook (California Department of Fish and Game, 1965). However, according to anecdotal information provided by anglers, "stray" chinook salmon inhabited low gradient reaches of the mainstem and larger tributaries

Coho were known to spawn and rear in 14 tributaries, but began to decline by the late 1960's and few were observed in the 1970's stream surveys. Cox (1994) reported that coho were known to have spawned and reared in the North Fork, Buckeye, Wheatfield Fork and South Fork subbasins, including the following areas: lower to middle reaches of the North Fork and Little North Fork, the middle reaches of Buckeye Creek, including Franchini Creek, the middle reaches of Wheatfield Fork, the larger Wheatfield Fork tributaries including Haupt, House, and Fuller Creeks, and Marshall and Sproule Creeks in the South Fork. Steelhead were found to be the most abundant species in a fish community composed of coho, roach, stickleback, sculpins and lampreys. DFG stocked the North Fork subbasin several times to increase coho spawning stock. The last recorded coho young-of the-year was in Dry Creek in 1998.

Surveys from the 1960's and 1970's found salmonids in considerably higher numbers and in a larger geographic area in the watershed. Due to a lack of quantitative information, historical population estimates of anadromous salmonids are unknown. However, based on anecdotal information, amount of historical and current suitable habitat, qualitative assessments, and comparisons with other north coast streams, it is highly probable that populations have declined compared to historical numbers throughout the watershed.

The 2001 electrofishing surveys showed that coho salmon were not observed in their historic tributaries and steelhead one year and older may have decreased in some tributaries in the watershed. Overall the watershed appears to be dominated by roach and steelhead young-of-the-year, with steelhead one year and older present, but in smaller numbers.

ADD FIGURES: BASIN HISTORIC AND CURRENT DISTRIBUTION

In 2001, the following tributaries were electrofished to identify species composition: North Fork; Little North Fork; Doty; Franchini; Wheatfield; House; Haupt; Pepperwood; and Tombs Creeks. Data indicated that differences in fish community structure exist between subbasins. The North Fork Basin was dominated by sculpin, roach and steelhead young of the year. Fish data was unavailable for the Rockpile subbasin. The Buckeye subbasin showed that Franchini Creek was dominated by steelhead one year and older in the middle and upper reaches with steelhead young-of the-year present. The Wheatfield subbasin was dominated by roach with few steelhead one year and older present. Very little of the South Fork was available to survey due to the lack of landowner access. Steelhead young of the year were dominant in the two reaches that were sampled. Further research and improved sampling strategies would greatly benefit stock assessment efforts.

ADD FIGURES: BASIN HISTORIC AND CURRENT DISTRIBUTION FROM EFISHING

TABLE 5: Fishery Resources of Gualala River

COMMON NAME	SCIENTIFIC NAME
ANADROMOUS	
Coho Salmon	*Oncorhynchus kisutch*
Steelhead Trout	*Oncorhynchus mykiss*
Pacific Lamprey	*Lampetra tridentata*
FRESHWATER	
Coastrange Sculpin	*Cottus aluticus*
Prickly Sculpin	*Cottus asper*
Threespine Stickleback	*Gasterosteus aculeatus*
MARINE OR ESTUARINEDEPENDENT	
Surf Smelt	*Hypomesus pretiosus*
Shiner Surfperch	*Cymatogaster aggregate*
Staghorn Sculpin	*Leptocottus armatus*
Starry Flounder	*Platicthys stellatus*
AMPHIBIANS	
Pacific giant salamander	*Dicamptodon tenebrosus*
Tailed Frog	*Ascaphus truei*
Red-Legged Frog	*Rana aurora*
Foothill Yellow-legged Frog	*Rana boylei*

Anadromous Salmonid Natural History

Steelhead

Steelhead trout are an anadromous strain of rainbow trout that migrate to sea and return to inland rivers as adults to spawn. In contrast to all Pacific salmon, not all steelhead die after spawning. U.S Fish and Wildlife service stated that a run of approximately 10,000 steelhead occurred in Gualala River in 1960 (USFW 1960). This is an uncertain estimate, for it was contrived from data relating to other streams of similar size and characteristics which were then applied to Gualala River. It is unknown if the Gualala River support different stocks of steelhead. Local fishermen remember three different stocks: winter run, “bluebacks” or “half-pounders”.

Generally, throughout their range in California, steelhead that are successful in surviving to adulthood spend at least (the most successful young steelhead spend from) two years in fresh water before emigrating downstream. In the Gualala River, steelhead generally migrate as 2-year old smolts during spring and early summer months. Emigration appears to be more closely associated with size than age, 6-8 inches being the size of most downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets.

In the Gualala River watershed, steelhead were the only species of salmonids observed in 2001 electrofishing surveys. All streams surveyed in the watershed contained steelhead populations of various concentrations (Brown 1988; DFG surveys 2001). Young of the year steelhead were the dominant age class found.

Steelhead numbers have diminished from historic numbers, whereas coho were not observed anywhere in the subbasin. The ability of steelhead to persist may be attributed to their ability to inhabit stream conditions that are available in many of the tributaries of Gualala River. These tributaries have steep gradients, migration barriers, lack of channel complexity, and exhibit higher water temperatures that limit production of coho salmon. Steelhead have displayed more adaptability to these conditions.

Coho Salmon

California coho salmon (*Oncorhynchus kisutch),* also known as silver salmon, are listed as threatened under the Federal Endangered Species Act (ESA; NMFS 1995). This listing has come as a response to the declining numbers throughout their southern range. A 1995 estimate stated that less than 5,000 wild coho salmon (no hatchery influence) spawned in California each year (Moyle et. al 1995). This is a drastic decline from statewide estimates in the 1940's, which assumed there was anywhere from 200,000 to one million adult coho in California (Calif. Advisory Committee on Salmon and Steelhead Trout 1988). Essentially, coho populations are less than 6% of what they were in the 1940's.

Coho salmon exhibit a three-year life cycle and do not appear to have the genetically distinct and spatially separated runs that other salmon and steelhead trout have displayed. After spending two years in the ocean, coho return to spawn in late fall and early winter following seasonally significant rains. As with other species of salmon, coho die after spawning. Unlike other salmon species, coho salmon redds can be situated in substrates composed up to 10% fines (Emmett, et al, 1991), but typically spawning success and fry survival are favored by very clean gravel consisting of less then 5% fines (CDFG 1991).

Juvenile coho typically spend one year in the freshwater streams before migrating out to the ocean. Consequently, adequate cover, cool water, high canopy density, and sufficient food to sustain them through their fry and juvenile stages become critical habitat components. Specifically, secondary channel habitats, such as cool, backwater pools with a large woody debris cover, are highly preferred habitat conditions for developing juvenile coho salmonids (CDFG 1991).

The Gualala River watershed, like other systems in California, have suffered declines or absent populations of coho. Coho were estimated to have a run of _____ spawners in 1960 (U.S. Fish and Wildlife 1960).

Fish History and Status

Fishing Interests, Constituents

In progress

Fish Restrictions, Acts, Protections

In progress

Fish Restoration Programs

In progress

Special Status Species

In progress

Ecological Management Decision Support (EMDS)

Introduction

This report is intended to be useful to landowners, watershed groups, and individuals to help guide land use and management decisions. As noted above, the assessment operates on multiple scales ranging from the detailed and specific stream reach level to the very general basin level scale. In the Gualala, for example, there is a general problem with elevated amounts of fine-grained sediment in lower gradient stream channels. These are reaches used by coho salmon and steelhead trout. This sediment is generally harmful to salmonid habitat as discussed above, and developed in the following discussion about the EMDS model.

This condition is not uncommon throughout most of the overall NCWAP coastal region. To improve that condition, and therefore salmonid habitat, will require long periods of time even with reduced levels of erosion brought about by careful watershed stewardship. A goal of this program is to help guide, and therefore accelerate that recovery, by focusing, stewardship and improvement activities where they will be most effective. Scaling down through finer levels guided by the recommendations should help accomplish this focus.

To do so, the report is constructed to help provide that focus of energy and other resources. A user can focus down from the general basin finding and recommendation concerning high sediment levels to the various subbasin sections, or the summary subbasin recommendation table to see if the general recommendation is applicable to a subbasin of interest. From there, if that is the case, the next step is to determine which streams in the subbasin may be affected by sediment. There is a list of surveyed streams in each subbasin section. In the general recommendation section, there is a tributary finding and recommendation summary table that indicates the findings and recommendations for the surveyed streams within the subbasin. From there, if indicated, field investigations at the stream reach or project site can be conducted to make an informed decision on a project, or design improvement activities.

For example in the Gualala Wheatfield fork Subbasin, sediment is an issue in the findings and recommendations. From the list of tributaries in the subbasin section the tributary table can be referred. House Creek is a Wheatfield fork Subbasin stream on that list that has both streambank and road sourced erosion as issues for treatment related to land use projects or improvement activities.

During the past two years, numerous landowners gave permission for erosion control surveys to be conducted on their lands in cooperation with the Gualala River Watershed Council and the DFG Restoration Grants Program based upon the recommendation in this DFG Stream Report. NCWAP, through its EMDS tool and resultant spatial presentation of its findings will provide the opportunity to conduct better coordinated stewardship and restoration work like this at the much broader, basin scale.

A NCWAP Tool for Data Synthesis

As part of the watershed assessment, the NCWAP team is using computer models called knowledge base or expert systems. These are tools that help scientists define how a complicated ecosystem, such as a watershed, functions. The software allows scientists to combine data of different environmental factors, such as stream temperature and substrate composition, to produce a synthesis of watershed conditions for native salmonids. The tools provide a consistent and repeatable approach to evaluating conditions across numerous watersheds in the region. The knowledge base modeling software requires scientists to identify and evaluate specific environmental factors or attributes which contribute to the formation of anadromous salmonid habitats.

For this purpose, the NCWAP will employ a linked set of software: NetWeaver, Ecological Management Decision Support (EMDS) and ArcView™. NetWeaver (Saunders and Miller (no date)), developed at Pennsylvania State University, helps scientists build graphics of networks that specify how the various environmental factors are incorporated into an overall stream or watershed assessment. These networks resemble branching tree-like flow charts, and graphically show the logic and assumptions used in the synthesis.

EMDS (Reynolds 1999), was developed by Dr. Keith Reynolds at the USDA-Forest Service, Pacific Northwest Research Station. It uses the networks created with NetWeaver in conjunction with environmental data stored in a geographic information system (ArcView™) to perform the assessments and facilitate rendering the results into maps. This combination of NetWeaver/EMDS/ArcView software is currently being used for watershed assessment within the federal lands included in the Northwest Forest Plan.

The Knowledge Base Network

For California's north coastal watersheds, the NCWAP scientists built two knowledge base networks using the best available scientific studies and information on how various environmental factors combine to affect anadromous fish on the north coast. The first, called the Stream Reach model, addresses conditions for salmon on individual stream reaches. The second, the Watershed Condition model, serves as a framework for synthesis by watershed of a number of environmental factors. In creating both of these networks, the NCWAP scientists have used what is termed a 'top-down' approach.

This is perhaps best explained by way of example. The NCWAP scientists start from the proposition that the overall condition of a given watershed is suitable for maintaining healthy populations of native salmon and trout, and through the design of the knowledge base (the network) seek to evaluate the 'truth' of that assertion. They then constructed a knowledge base network is to specify the types of information needed to test the proposition, and how each will be used.

The 'ingredients', or data, needed for the assessment are broken down into categories. To evaluate watershed conditions for salmonids, the scientists specified that data are required on several general environmental factors. The knowledge base network (figure 1) shows that information on upland condition, roads, passage barriers, and stream condition factors are all needed in the watershed assessment. The 'AND' decision node (where the factors are combined) means that each of the four general factors must be suitable for the fish for the 'watershed is suitable for native salmonids' proposition to be evaluated as completely 'true'.

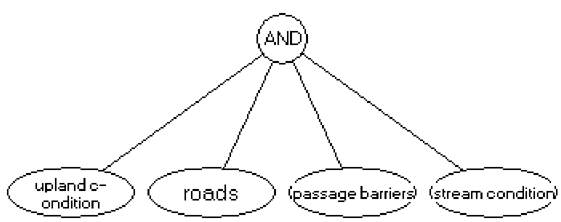


FIGURE 5

The Knowledge Base is for Assessing Watershed Conditions for Native Salmonids. Each of the Elliptical Boxes Shows a Factor Used in the Assessment and Lines Indicate How They are Linked to the "AND" Node Where They are Compared.

In a similar manner, each of the four main environmental factor is actually made up of smaller constituent components. For example, in the NCWAP Watershed Condition model the 'upland condition' factor consists of a sub-network of more detailed data on land use, land cover (vegetation) and slope stability that determine it (not shown in the above figure). Information in the sub-network that determines land use includes data on developed area, cultivated area, grazed area and area of timber harvests. In knowledge bases, this pattern of logic networks can be expanded up or down as much as desired, until there is a full picture of all factors affecting salmonid conditions in the watershed. The beginning boxes (end branches) in a knowledge base network are where the data is entered.

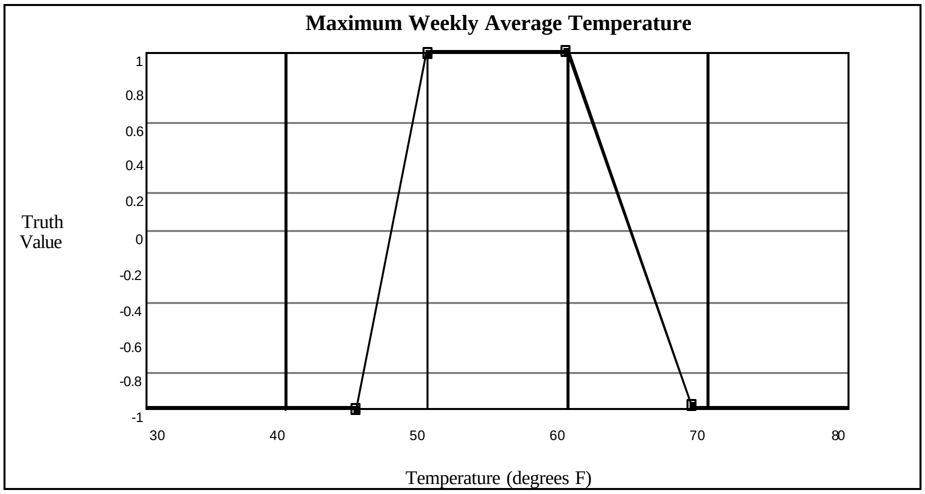


FIGURE 6: Relationship between Water Temperature and Suitability for Salmon

EMDS Uses this Type of Function in Conjunction with Data to Evaluate a Proposition, in this Case that "Water Temperature is Suitable for Native Salmon and Trout."

Wherever there is a proposition in the network, scientists use simple graphs that determine its degree of truth, according to the data and its implications for salmon. Figure 2 shows an example, where the proposition is "the stream temperature is suitable for salmon". The horizontal axis shows temperature in degrees Fahrenheit, while the vertical is labeled 'Truth Value' and ranges from –1 to +1. The line shows what are completely unsuitable temperatures (-1), completely suitable temperatures (+1) and those that are in-between (> -1 and <+1). In this way, similar graphic relations are created for all propositions in the EMDS evaluation.

For all evaluated propositions in the network, the results are a number between –1 and +1. The number shows the degree to which the data support or refute the 'conditions are suitable' proposition. In all cases a value of +1 means that the proposition is 'completely true', and –1 implies that it is 'completely false', with in-between values indicate 'degrees of truth' (i.e. values approaching +1 being closer to true and those approaching –1 converging on completely untrue). A zero value means that the proposition cannot be evaluated based upon the data available. Breakpoints (where slope of function changes) in the figure 2 example occur at 45, 50, 60 and 68 degrees F. The NCWAP fisheries biologists determined these temperatures by a search of the scientific literature.

In EMDS, the data that is fed to the knowledge base network comes from GIS layers stored and displayed in ArcView. Thus many of the GIS data layers developed for the program will be used directly in the watershed condition syntheses.

Advantages Offered By Netweaver/EMDS/ArcView Software

The NetWeaver/EMDS/ArcView software offers a number of advantages for use in the NCWAP. At this time no other widely available package allows a knowledge base network to be linked directly with a geographic information system such as ArcView. This link is vital to the production of maps and other graphics reporting the watershed assessments.

The graphs and NetWeaver-based flow diagrams required that the NCWAP scientists be forthright and explicit in how they have defined suitable conditions for salmonids needed for the completion of their lifecycle. The process was thus formalized and quantified, and is now repeatable systematically throughout the assessments of all watersheds. Equally important, the nature of the networks assists open communication to the general public through simple graphics and easily understood flow diagrams.

Another feature of the system is the ease of running alternative scenarios. Scientists and others can test the sensitivity of the assessments (i.e. perform 'sensitivity analyses') to different assumptions about the environmental factors and how they interact, through changing the knowledge-based network and breakpoints. 'What-if' scenarios can be run by changing the shapes of curves (e.g. figure 2) at the base level, or by changing the way the data are combined and synthesized in the network.

NetWeaver/EMDS/ArcView tools can be applied to any scale of analysis, from reach specific to entire watersheds. The spatial scale can be set according to the spatial domain of the data selected for use and issue(s) of concern. Alternatively, through additional network development, smaller scale analyses (i.e. subwatersheds) can be aggregated into a large hydrologic unit. With sufficient sampling and data, analyses can even be done upon single or multiple stream reaches.

NetWeaver ranks the environmental factors (given the logic and environmental factors <-> conditions relationships) by their influence on the overall habitat indicator values derived. They also show which factors, with more complete and comprehensive data, would improve the quality of the analysis in the most cost-effective manner.

EMDS and NetWeaver are public domain software (NetWeaver on a trial basis), available to anyone at no cost over the Internet. Although the NCWAP will employ EMDS and NetWeaver for watershed synthesis, this is not meant to preclude the use of other knowledge base expert systems, approaches, or models for further exploration of fish-environment relationships.

Management applications of watershed synthesis results

While EMDS-based syntheses are important tools for watershed assessment, they do not by themselves yield a course of action for management. EMDS results will require interpretation, and how they are employed depends upon other important issues, such as social and economic concerns. In addition to the accuracy of the expert opinion and knowledge base system constructed, the currency and completeness of the data available for a stream or watershed will strongly influence the degree of confidence in the results.

The output from EMDS Watershed and Stream Reach models will be used to support several levels of planning. At the regional level, the State anticipates the NCWAP analyses to be incorporated into coho, chinook, and steelhead recovery plans being developed by National Marine Fisheries Service (NMFS). It will provide a finer level of detail than factors identified at the Evolutionary Significant Unit (ESU) or domain level. This can assist recovery plan development, to focus on appropriate conditions and potential corrective actions by landowners and others. The results of the synthesis will also aid watershed level planning by watershed groups and others. It can provide direction for developing a strategy and sequence for fixing habitat “bottlenecks” to salmonid production or health.

EMDS syntheses can be used at the basin scale, to show current watershed status. Maps depicting those factors that may be the largest impediments, as well as those areas where conditions are very good, can help guide protection and restoration strategies. The EMDS model can also help to assess the cost-effectiveness of different restoration strategies. By running sensitivity analyses on the effects of changing different habitat conditions, it can help decision makers determine how much effort is needed to significantly improve a given factor in a watershed and whether the investment is cost-effective.

At the project planning level, the model results can help landowners, watershed groups and others select the appropriate types of restoration projects and places (i.e., planning watersheds or larger) that can best contribute to recovery. Agencies will also use the information when reviewing projects on a watershed basis.

The main strength of using NetWeaver/EMDS/ArcView knowledge base software in performing LFAs is its flexibility, and that through explicit logic, easily communicated graphics and repeatable results, it can provide insights as to the relative importance of the constraints limiting salmonids in North Coast watersheds. In the NCWAP, the analyses will be used not only for assessing conditions for fish in the watersheds and to help prioritize restoration efforts, but also to facilitate an improved understanding of the complex relationships between environmental factors, human activities, and overall habitat quality for native salmon and trout.

EMDS in the Gualala River Assessment

Note to the reader: The final EMDS model was analyzed for the Northfork subasin. The other subbasins will be addressed in the next version of the synthesis report. The results are contained in the appendix.